NARROW BOX GIRDER BRIDGES TECHNOLOGY

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ABSTRACT

The narrow box girder bridge is a rationalized box girder bridge that is characterized by simplification of the structure inside the box by reducing longitudinal and transverse ribs and elimination of the floor framing by using highly rigid steel and concrete composite deck slabs. This type of bridge features excellent maintainability because of its simple structure, improved aesthetic appearance, and great ease in terms of local constructability. This report explains the technology and outlines actual applications.

1. INTRODUCTION

The narrow box girder bridge is a rationalized box girder bridge in which the structure inside the box is simplified by using a thicker flange and a narrower web distance of the box section than conventional box girders and rationalization is also sought by using a highly rigid steel-concrete composite deck. This type of bridge features excellent maintainability, improved aesthetic appearance and very good site constructability. Details and cases of construction are presented here.

2. STRUCTURAL FEATURES OF NARROW BOX GIRDER[1)]

The narrow box girder is a rationalized box girder that has structural features such as simplification inside the box and omission of the floor framing, and being adaptable to curves and long spans as well as being applicable to wide and widened decks.

Figure 1 shows a comparison with the conventional structure and Figure 2 shows an itemized comparison with a conventional bridge.

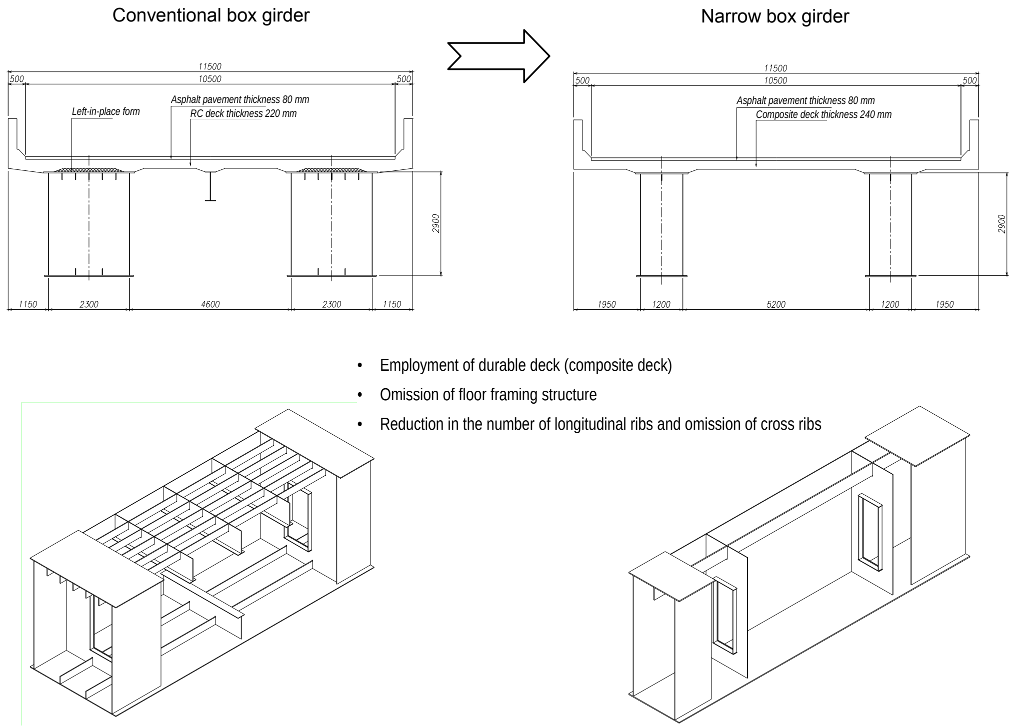


Figure 1. Comparison with conventional structure

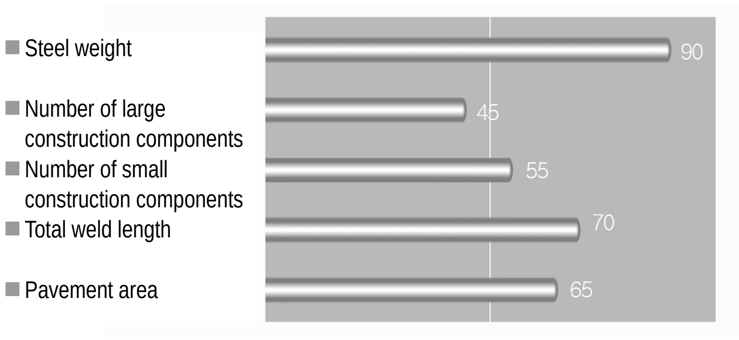


Figure 2. Itemized comparison with conventional bridge

2.1 Reduction in fabrication and erection costs and construction period

1) Rationalization of main girder

By reducing the web distance, the longitudinal and cross ribs can be omitted, achieving a substantial reduction in the number of construction components.

2) Omission of floor framing

By using a highly rigid steel-concrete composite deck or PC deck, the deck span can be extended and the floor framing can be omitted.

2.2 Improved safety

Deck formwork, deck safety facilities and other work under the deck can be omitted, resulting in a reduced construction period and improved safety.

2.3 Maintenance cost reduction

1) Reduction in painting area

Stiffeners and floor structure can be omitted and a reduction in painting area can be achieved.

2) Improvement in deck durability

Deck repair cost can be reduced by using a durable deck.

2.4 Improvement in aesthetic appearance

Because of the reduced number of floor framing members, the appearance becomes simple and the aesthetic appearance is improved.

3. MATTERS TO BE VERIFIED AND EXAMINED REGARDING NARROW BOX GIRDER BRIDGES

The narrow box girder stated in Section 2 is a conventional box girder bridge with a simplified structure, so there are some items to which conventional standards cannot be applied as they are. Therefore, when using a narrow box girder bridge, these items must be fully examined.

3.1 Stiffening design of narrow box girder section

Longitudinal ribs must be placed at the necessary intervals on the compression flanges of a conventional box girder bridge to prevent buckling and ensure the allowable stress is not exceeded. Cross ribs also had to be placed.

On a narrow box girder bridge, the narrow web distance resulted in a small flange width, so the flange thickness had to be increased. This allowed the number of longitudinal ribs to be reduced. Figure 3 shows the required number of longitudinal ribs with respect to web distance for a constant

flange cross-sectional area. On a conventional box girder bridge, the web distance is 2000 mm or so and three longitudinal ribs are needed, while on a narrow box girder bridge with a web distance of 1200 mm, longitudinal ribs can be omitted.

The required stiffness of a longitudinal rib on a compression flange is constant regardless of cross rib spacing (Figure 4), so the cross ribs become unnecessary.[2)]

For ease of work inside the box during fabrication, the minimum web distance is suggested to be 1.2 m or so.

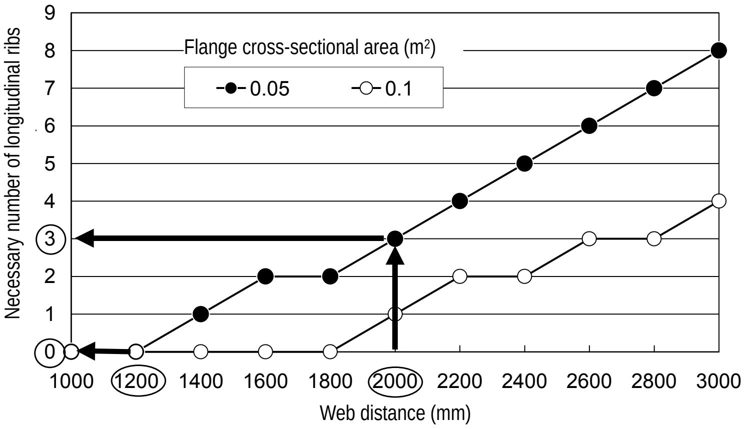


Figure 3. Necessary number of longitudinal ribs to web distance and flange thickness (SM490Y)

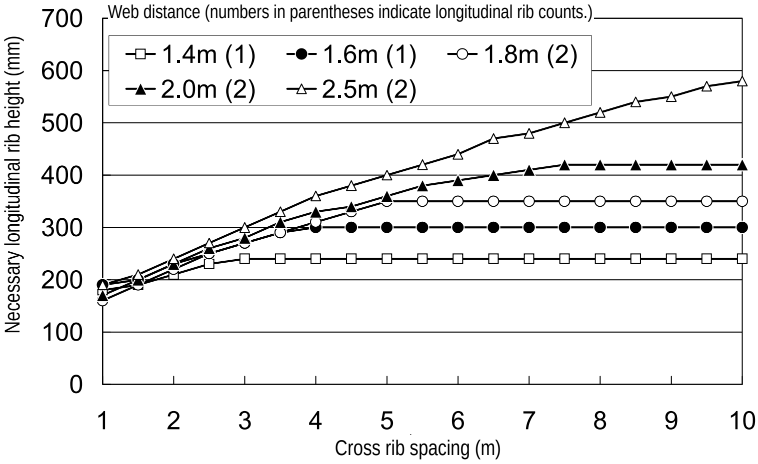


Figure 4. Cross rib spacing and necessary longitudinal rib height to web distance

3.2 Application to curved girder

When applying the narrow box girder bridge concept to a curved bridge, the same design as a conventional box girder bridge can be used. However, the cross-sectional shape is vertically long and the torsional resistance and out-of-plane stiffness are less than conventional box girders, so it became necessary to check for lateral buckling and examine additional stresses in the main girder flanges.

1) Check for lateral buckling

A comparison of the sectional quantities and lateral torsional buckling moments of I-section girders and narrow box girders with the same vertical bending stiffness is shown in Table 1. The second moment of the area about a vertical axis is about 12 times as large and the pure torsion constant is about 6,000 times as large for narrow box girders. As a result, the lateral torsional buckling moment is about 25 times as large, that is to say the order of magnitude in difference is a two-digit number larger than the value of the yield moment. Thus, it is reasonable to assume that there is no possibility of lateral torsional buckling.

2) Additional stress on main girder flange

The additional stress due to curvature was calculated for a three-span continuous narrow box girder bridge (65 + 80 + 65 m R = ∞, 500 m, 300 m). The relationship with bending stress is shown in Table 2.

At a curvature of R=300 m, the additional stress increases to 8.5 percent of the bending stress at maximum; however, about 3 or 4 percent of the bending stress occurs even at R= ∞, so the effect of curvature is 5 percent or less. For the radius of curvature applied to ordinary box girder bridges, the additional stress due to the flange curvature causes no problems. In other words, the stress increase due to the occurrence of additional stress is trifling compared to a straight girder.
These things indicate that the narrow box girder has the same performance as a conventional box girder.

Table 1. Comparison in various section quantities between I-section girder and narrow box girder

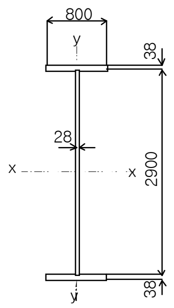
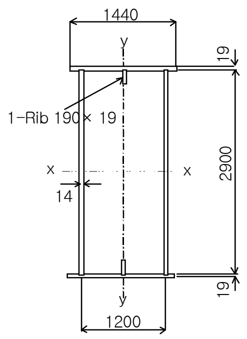
	I-girder	Narrow box girder	Ratio (narrow box girder/I-girder)
Sectional shape			
Cross-sectional area A (m^2)	0.1420	0.1431	1.01
Second moment of area about horizontal axis I_V (m^4)	0.1881	0.1867	0.99
Second moment of area about vertical axis I_V (m^4)	0.00324	0.03869	11.9
Pure torsional constant J (m^4)	0.00002	0.09034	6023
Warping torsional constant C_W (m^4)	0.00700	0.00932	1.33
Yield moment M_y (kN • m)	26,548	26,693	1.01
Elastic lateral torsional buckling moment, M0cr (kN • m), in the case of L = 10 m	94,340	2,336,051	24.8

Table 2. Comparison of stress occurring in lower flange of G1 girder

	R=∞		R=500m		R=300m	
	Intermediate support	Span center	Intermediate support	Span center	Intermediate support	Span center
M_y(kN･m)	−62181	36124	−63444	37132	−64396	37789
M_w(kN･m^2)	318.3	−318.3	527.3	−379.0	594.0	−474.9
σ_y(N/mm^2)	−257.1	179.2	−262.3	184.2	−266.2	187.4
σ_w(N/mm^2)	7.8	6.6	12.9	13.7	14.6	15.9
σ_w / σ_y	3.0%	3.7%	4.9%	7.4%	5.5%	8.5%

3.3 Omission and simplification of intermediate transverse girder structure

The bending rigidity of the deck has a large effect on the load distribution in a juxtaposed box girder bridge; however, the effect of whether there are intermediate transverse girders or not is small or insignificant at most. Therefore, the intermediate transverse girders can be omitted.
However, considering erection and repair, it is best to install intermediate transverse girders.
Section 4.2 presents a case in which the intermediate transverse girders are omitted.

3.4 Deck design stress resultant

The deck of a narrow box girder bridge is supposed to be placed covering the entire flange surface. Assuming a box girder spacing of 6 meters or so, an examination by three-dimensional FEM analysis was performed to find out whether the design bending moment in a deck span would show the behavior of a simple slab.

The results of the deck bending moment obtained by three-dimensional FEM analysis were compared with the bending moment as though it were a continuous deck given in the Specifications for Highway Bridges with Commentaries (the Bridge Specifications hereinafter) and the Guidelines for Design of Steel Structures, Part B (Part B hereinafter) by the Japan Society of Civil Engineers.

For both live and dead loads, the FEM analysis results were found to have a margin of 30 to 50 percent or so with respect to the bending moment given in the Bridge Specifications and Part B (Figures 5 and 6). Accordingly, it could be verified that the design bending moment was well on the safe side even if the moments in a continuous deck were used.

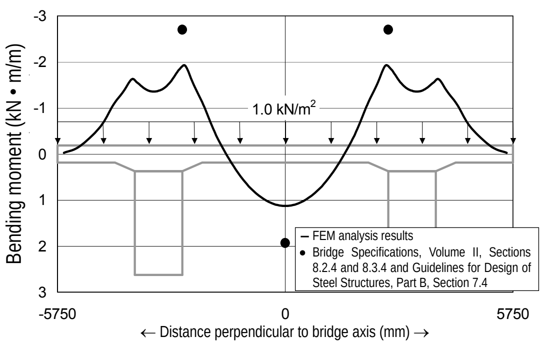


Figure 5. Bending moment distribution in deck (distributed load)

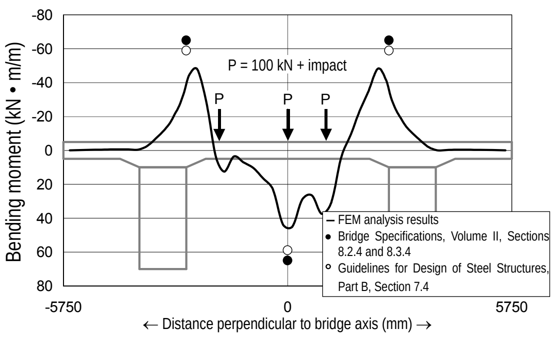


Figure 6. Bending moment distribution in deck (live load)

3.5 Aerodynamic stability

No systematic wind tunnel tests have been conducted before for the aerodynamic stability of a deck with a narrow box section. Thus, a wind tunnel test of a narrow girder box bridge was conducted to verify its safety.

For details, see the report “Wind Tunnel Test and Real Bridge Vibration Test of Narrow Box Girder Bridges.”

4. CASES OF CONSTRUCTION

Of the cases of narrow box girder construction, the Inasa Junction whose work was done at the beginning of its being used and the 503rd and 504th construction sections whose work was done recently are presented here.

4.1 Inasa Junction[3)]

(1) Structure summary

For the Inasa Junction, a study was conducted by economic comparison with the conventional box girder structure and, as a result, the narrow box girder structure was used because of the possibility of substantial omission of small construction components and economic superiority. A structure summary is given below. Photograph 1 shows the site situation and Figure 7 shows general drawings.

Route name:	Daini Tokai Expressway, Yokohama-Nagoya Line
Type:	Simple steel composite narrow box girder bridge
Bridge length:	65.5 m
Total width:	20.7 to 21.8 m
Effective width:	17.9 to 19.6 m
Deck type:	PRC deck (cast-in-place)
PC steel:	Pregrouted PC steel

Photograph 1. Inasa Junction

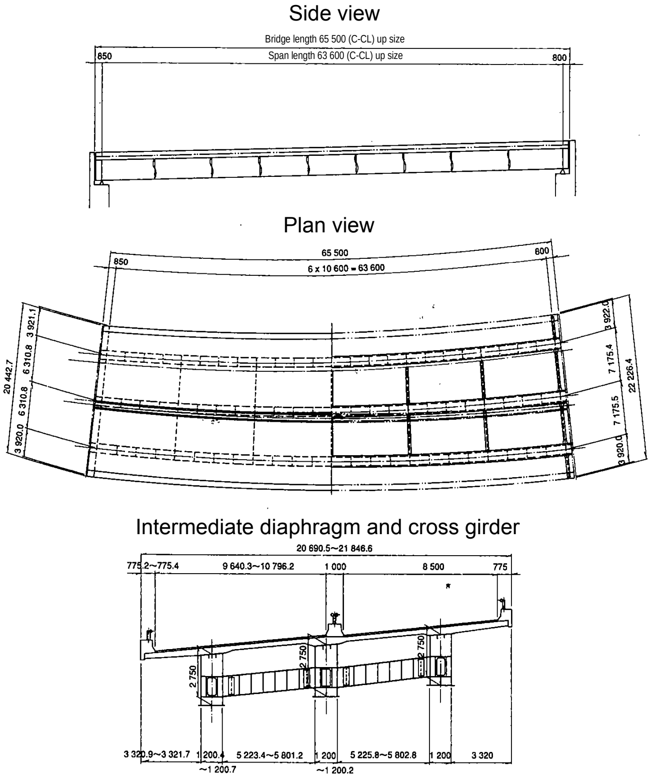


Figure 7. General structure of Inasa Junction

(2) Design summary

1) Main girder

As a composite girder, the section forces were calculated by plane frame analysis in order to determine the sections. The horizontal stiffeners were omitted due to economical considerations.

2) Cross girder

To reduce the resistance by the cross girder when introducing cable tension into the deck, the installation positions of cross girders were at the lower part of the main girders and the spacing was taken to be 10 meters or so.

3) PRC deck

In consideration of designing on the safe side, the design of the PRC deck was done by making a model of the deck as completely fixed to the box girders.

4) FEM analysis

FEM analysis was performed to confirm the introduction of prestress and confirm the integrity assessment of the stud dowels on the main girders. As a result, it was confirmed that the planned prestress would be introduced at both the cross girder position and the center position between cross girders. And, safety was confirmed because the stress occurring in the stud dowels was sufficiently below the allowable stress.

(3) Site construction

A staging method using bents and an 800-ton lifting crawler crane was used to erect the bridge. Photograph 2 shows a view of the ground assembly of a main girder and Photograph 3 shows a view of the construction site.

Photograph 2. View of ground assembly of main girder

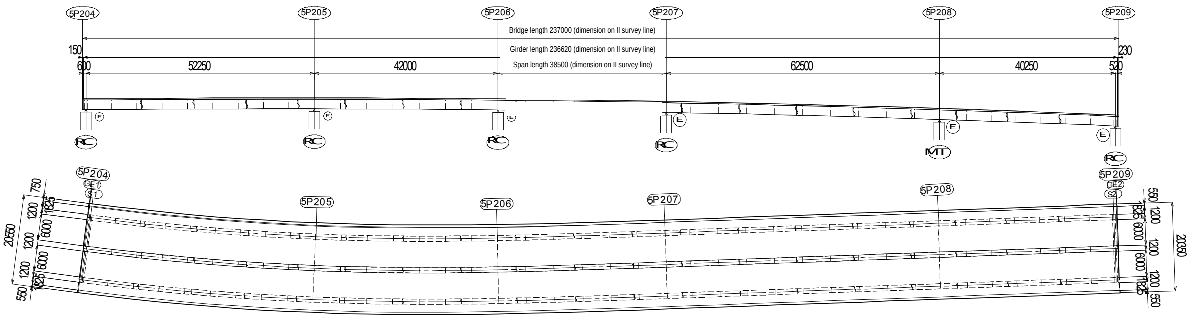
Photograph 3. View of site construction

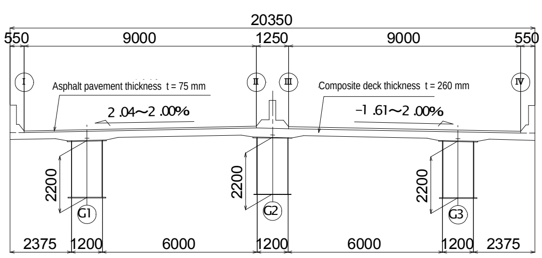
4.2 503rd and 504th construction sections

(1) Structure summary

For the 503rd and 504th construction sections of Fukuoka Expressway Route 5, the economy of different sectional configurations was compared taking a mean span length of 60 meters and as a result, a continuous composite narrow box girder bridge with an integral structure of up and down lanes was used. In these construction sections, substantial rationalization was attempted by using a steel-concrete composite deck of high rigidity and thus reducing the number of longitudinal and intermediate cross girders. Because there is no floor framing or stiffener, the structure is excellent in maintenance, simplicity and aesthetic appearance.

The structure summary of the 503rd and 504th construction sections is given below. Figure 8 shows a general drawing of the (Katae) viaduct in the 503rd construction section.





Route name:	Fukuoka Expressway Route 5
Type:	5-span continuous steel composite narrow box girder bridge
Bridge length:	237.00 m
Total width:	20.35 m (normal portion) (integral structure of up and down lanes)
Effective width:	9 m + 9 m (normal portion)
Deck type:	Steel-concrete composite deck

Figure 8. General structural drawing of 503rd construction section

(2) Structural features

An examination was performed on the narrow box girder of Fukuoka Expressway Route 5:
1) Omission of intermediate cross girders, 2) Design of the dowel, and 3) Design of the cross girder on a support.

1) Omission of intermediate cross girders[4)]

On the narrow box girder, using a composite deck of high rigidity allowed the intermediate cross girders to be omitted. For verification, an analysis was performed to find out the effect of this omission on the load distribution between main girders and on the deck.

The structural analysis was performed on the steel girder and composite deck after modeling them separately. By using a constant shear flow panel, the effect of eccentric connections between the deck and main girders and the characteristics of the deck as a slab structure could be analyzed efficiently. The analytical model was a three-main girder bridge with an integral structure of up and down lanes and with a total width of 20.35 meters, deck spans of 6 meters or more, and a length of 150 meters. The analysis was performed for a straight bridge and a curved bridge with a radius of curvature of 500 meters and for bridges with and without intermediate cross girders. Analysis results are shown below.

① Live load deflection at girder center

The effect of the presence or absence of cross girders on the amount of deformation of the main girder due to L-load is shown in Table 3.

Table 3. Effect of presence or absence of cross girders on live load deflection

Allowable deflection = $L/500$ = 100 mm

max	Straight			Curved		
	cross girders absent	cross girders present	Ratio of absence/presence	cross girders absent	cross girders present	Ratio of absence/presence
G_1	25.71	25.10	1.02	24.58	23.84	1.03
G_2	21.32	20.48	1.04	21.39	20.56	1.04
G_3	25.71	25.10	1.02	26.89	26.30	1.02

Regardless of whether the bridge was straight or curved, the effect of transverse girders was confirmed to be very small (1.02 to 1.04 times).

② Bending moment of main girder

The effect of the presence or absence of cross girders on the bending moment due to dead load after being connected and L-load is shown in Table 4. As with live load deflection, the effect of the presence or absence of cross girders is conceivably small regardless of whether the bridge is straight or curved.

Table 4. Effect of presence or absence of cross girders on bending moment of main girder

Dead load after connection + Live load (max, min)			Straight			Curved		
			cross girders absent	cross girders present	Ratio of absence/presence	cross girders absent	cross girders present	Ratio of absence/presence
G_1	min	Point P1	−7 911	−7 768	1.02	−7 673	−7 529	1.02
	max	Center of side span	5 847	5 712	1.02	5 730	5 579	1.03
G_2	min	Point P1	−5 953	−5 892	1.01	−5 963	−5 907	1.01
	max	Center of side span	4 674	4 636	1.01	4 676	4 640	1.01
G_3	min	Point P1	−7 911	−7 768	1.02	−8 156	−7 997	1.02
	max	Center of side span	5 847	5 712	1.02	5 945	5 818	1.02

③ Bending moment of deck at span center

The bending moment of the deck due to dead load after being connected and L-load is shown in Figures 9 and 10. In these moment diagrams, no large difference is seen between the presence and absence of cross girders. The difference in bending moment between the presence and absence of cross girders becomes large at the positions directly on the cross girders; however, its value is less than the allowable section force of the composite deck and can be assumed to cause no problems.

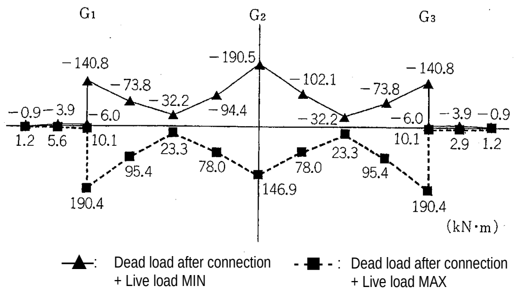


Figure 9. Bending moment of deck member C5 (straight bridge without cross girders)

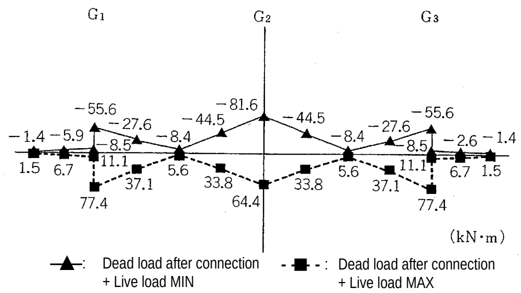


Figure 10. Bending moment of deck member C5 (straight bridge with cross girders)

④ Bending moment of deck due to T-live load

For the bending moment of the deck due to T-load, a comparison paying attention to the effect of cross girders is shown in Figure 11. With cross girders, the positive bending moment in a span tends to decrease while the negative bending moment at supports tends to increase. This is because the main girders are kept from rotating by the cross girders and accordingly the degree of rotational restraints on the deck increases.

Because composite decks are basically strong against positive bending and weak against negative bending, a structure without cross girders is advantageous for composite decks.

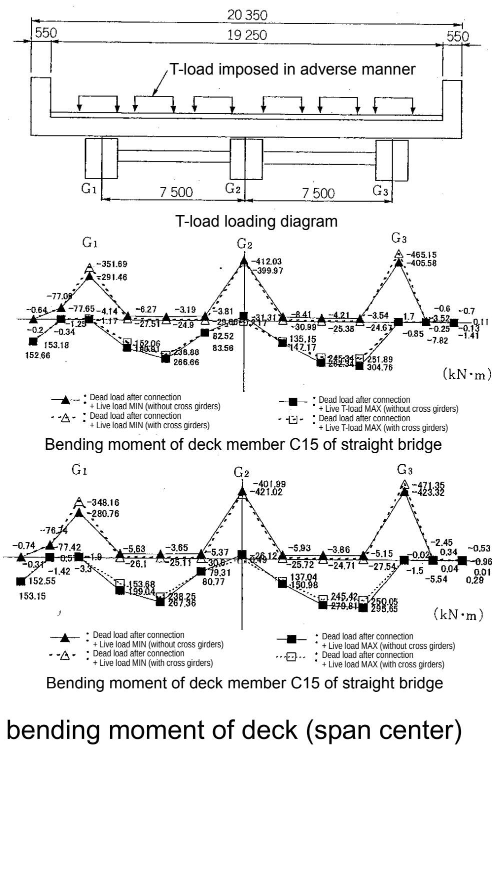


Figure 11. Effect of T-load on bending moment of deck (span center)

2) Dowel design

The dowels to be installed in the upper flange of the main girders were intended to give the composite deck a load distribution function, so the analysis was performed not only for shear forces parallel to the bridge axis, but also for horizontal forces perpendicular to the bridge axis.

Experimental methods and FEM analysis can be used to calculate horizontal forces perpendicular to the bridge axis, in this case the latter was used. An ordinary headed stud was used as the dowel member in the examination.

The above-stated examination results confirm that there would be no problem with fatigue due to shear forces and axial forces in the implementation design.

3) Design of cross girder on supports

The cross girder on a support is an important member for transferring lateral loads to the bearing and substructure. In order to analyze it, a model similar to the section force calculation model for the studs near a support was used to calculate section forces, which in turn were used to make the design. As shown in Figure 12, the wind load and horizontal seismic load were applied to the deck and the cross girder on a support after dividing these loads according to the rigidity ratio of the cross girder to the deck.

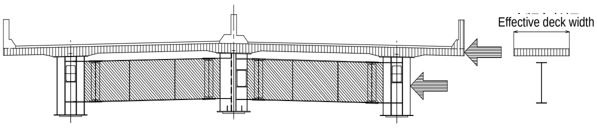


Figure 12. Design forces on cross girder on support

(3) Site construction of main girder and composite deck

An erection method using track cranes and bents was used for the erection of the main girders and composite deck in the 503rd and 504th construction sections. However, because this method involves traffic regulations on the street, slide erection was sometimes needed depending on the congestion of the lanes to be regulated. Views of slide erection are shown in Photographs 4 and 5.

Photograph 4. View of erection before sliding

Photograph 5. View of erection after sliding

5. CONCLUSIONS

The Inasa Junction and Fukuoka Expressway Route 5 were presented as representing the features of the narrow box girder and as a case of actual construction. The narrow box girder can be applied not only to curved bridges, but also to wide road widths and widened girders by freely setting the number of girders and girder spacing. Thus, this method has much freedom of design and can therefore be expected to be the method of choice for rationalized bridges.

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